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Short communication

Evaluating the perceived visual complexity of multidirectional hill-shading

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Abstract: Eye tracking recordings could reveal the visual behavior for different cartographic visualization techniques, such as hill-shading, while at the same time eye tracking metrics (ETMs) can summarize the associated complexity levels in a concise and quantitative manner. In the present study, three different hill-shading methods, including: (i) the standard method based on ideal diffuse reflection, (ii) the Multidirectional Oblique-Weighted method – MDOW and (iii) the combination of a MDOW's variation with standard hill-shading, are evaluated and ranked in terms of their perceived visual complexity. The performed examination is based on both eye tracking techniques and expert judgement procedures. A weighted combination of basic ETMs has been used, implemented by the Landscape Rating Index – LRI. The weights resulted from an experts' judgement process where the opinions of experts in geoinformatics, cartography, geovisualization, experimental psychology, cognitive science, neuroscience and eye tracking were analyzed. Fifteen (15) individuals participated in an eye tracking experiment with hill-shading images produced by the three methods under evaluation, while 41 experts participated in an online questionnaire in order to collect all the analysis data. The final evaluation was based on the computation of three LRI models. The outcomes indicate that implementing hill-shading with more than one light sources results in similar perceptual behaviors, allowing for a seamless exploitation of the advantages of using multidirectional illumination.

Keywords: multidirectional hill-shading, visual complexity, eye movement analysis, expert judgement process

1. Introduction

Hill-shading is the most realistic method used for the representation of topographic relief in maps, based on the simulation of tone variation taking place on earth's surface under favorable conditions of sunlight. It is far more superior compared to the hypsometric contour lines, as it can reveal individual shapes and the complete form at the same time (Imhof, 1982), while it gives an immediate appreciation for the topography, facilitating quick comprehension when time is limited or users are not trained cartographers (Horn, 1981). Traditional computer-generated hill-shading is made with single-source illumination, which is not effective on structures that are illuminated along their structural grain or on areas left in darkness (Mark, 1992). Applying more than one light source can help to represent more details of relief formations and to eliminate deep dark tones hiding topographic information (Loissios et al., 2007). While there are several research studies that examine hill-shading towards this direction (e.g. Kennelly and Stewart, 2006; 2014; Veronesi and Hurni, 2015), it was firstly introduced by Mark (1992) with MDOW method (Multidirectional Oblique-Weighted), based on a weighted combination of four individual hill-shading images illuminated from North, North–West, West and South–West directions. The visual result of using many light sources might look different compared to classic relief-shaded representation, and this might affect the process of perception in terms of visual complexity. This has been very recently confirmed by Farmakis-Serebryakova and Hurni (2020) who conclude that MDOW method, as evaluated in an online survey of perceived effectiveness of a selection of analytical relief shading methods, is too much detailed for most of landform types.

Visual complexity constitutes a critical factor that could influence the human visual perception and behavior during the observation of different types of visual stimuli (Machado et al., 2015). Regarding the preference of pictorial representations, visual complexity has been described as the richness of a setting or the amount of information that is available to look and to think about (Kaplan and Kaplan, 1989). In addition, according to Kuper (2017: 407), "attributes of complexity may include numerous, distinct colors, textures, shapes, and physical dimensions of foliage, flowers, path materials, topography, and structures". The influence of such attributes in human perception could be examined and evaluated through the performance of perceptual experiments. Among the existing methods, eye tracking procedures and eye movement analyses are considered modern and objective approaches for the examination of human visual perception, with applications in different research domains. Over the last decades, the influence of these methods in cartographic research is clear, considering the numerous existing studies related to map reading process (Krassanakis and Cybulski, 2019).

It is equally important, however, to develop appropriate and objective measures for examination of both features and design complexity (Pieters et al., 2010). Considering that more measures can substantially contribute to the better comprehension of how human visual strategies work (Kiefer et al., 2017), the further development of both quantitative and qualitative metrics could help towards this direction. Simultaneously, the concurrent utilization of both objective and subjective aspects could be achieved by the application of a mixed approach which combines both experimental data and experts' opinions.

Summarizing the above, eye tracking recordings could reveal the visual behavior for different cartographic visualization techniques, such as hill-shading, while at the same time eye tracking metrics (ETMs) can summarize the associated complexity levels in a concise and quantitative manner. In the present study, three different hill-shading methods are evaluated and ranked in terms of their perceived visual complexity; (i) the standard method based on ideal diffuse reflection, (ii) the Multidirectional Oblique-Weighted method – MDOW (Mark, 1992), and (iii) the combination of a MDOW's variation with standard hill-shading (Loissios et al., 2007).

2. Methods and data

The performed examination is based on the computation of the integrated Landscape Rating Index which combines metrics derived by eye tracking techniques and opinions adapted by expert judgement procedures, while it is implemented into two separate parts. More specifically, the study combines gaze data collected through the performance of an eye tracking experiment and opinions expressed by researchers of the field obtained by an online questionnaire.

2.1. The Landscape Rating Index

Recently, Krassanakis et al. (2018) proposed a new simple rating index, called "LRI (Landscape Rating Index)", suitable for the evaluation and ranking of different landscapes' images. The computation of LRI is based on the aggregation of measured (objective) ETMs with rating (subjective) weights produced by expert judgement procedures. Each rating weight indicates the contribution of different ETMs during the evaluation of different visual stimuli according to a specific concept. For example, such a concept could be directly related to the perceived visual complexity produced during the observation of different types of stimuli. The general formula of LRI is given in the following Eq. (1):

$$\mathrm{LRI} = \frac{\sum_{i=1}^{n} (x_i \times m_i)}{\sum_{i=1}^{n} |w_i|} \tag{1}$$

where the m_i variables correspond to the average values of the ETMs normalized (following the linear model) in the range between 0 and 1, w_i variables constitute the rating weights expressed after normalization in the range between -1 and 1, i corresponds to the n examined ETMs, while the values of the index lie between -1 and 1. The application of the index is based on the adaptation of an LRI model which includes the ETMs which are considered relevant to the examined concept (e.g. visual complexity), while the computation of the corresponding LRI values for each experimental stimuli can be used for their direct comparison and ranking.

2.2. Eye tracking experimental design

2.2.1. Stimuli

Three different areas in Greece were selected due to a wide variety of terrain forms and directions to serve the purpose of evaluation in alternative conditions of topographic relief. They include "Perista" ("Per") and "Kastania" ("Kas") areas (placed at Karpenissi, Central Greece) which contain several linear formations with finer details and "Zarouchla" ("Zar") area (placed at Kalavryta, Peloponnisos) that involves compact, smoother forms. In total, nine stimuli were designed (Fig. 1) based on the application of three different hill-shading method in each of three regions including (a) the ideal diffuse reflection method ("Std"), (b) the MDOW method ("Mdw"); and (c) the combination of ideal diffuse reflection and MDOW variant ("Lab"). In all hill-shading methods applied, the light sources were located under 45° of altitude angle. The azimuth angle of single light source position for ideal diffusion used in methods (a) and (c) was 315° (it is reminded that MDOW implementations use four light sources placed at North, North–West, West and South–West directions).

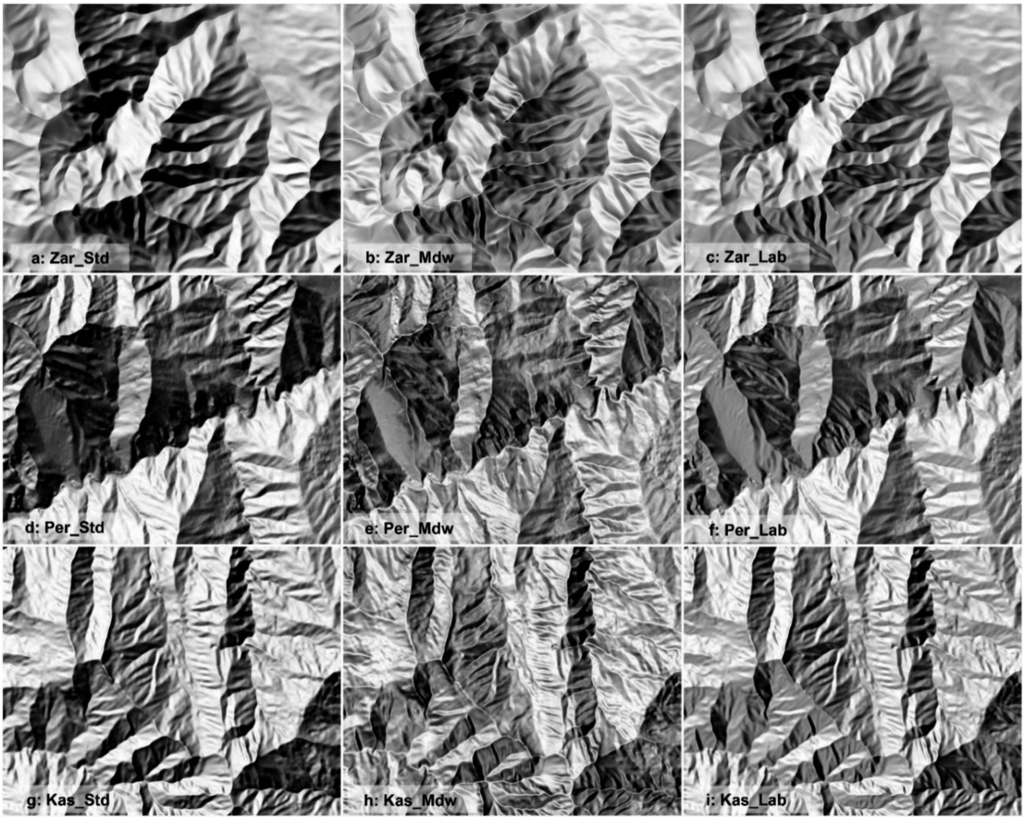

Fig. 1. Experimental stimuli

2.2.2. Setup and selected parameters

The Viewpoint Eye Tracker® by Arrington Research was used for the collection of gaze data in the sampling frequency of 60 Hz. The spatial accuracy of the eye tracking device lies between the range of $0.25^\circ - 1^\circ$ of visual angle, while the distance between the participant and the stimuli monitor corresponds to approximately 60 cm (a chin rest mechanism is also used in order to achieve the optimal levels of spatial accuracy). All stimuli were presented on a 19-inch computer monitor with 1280×1024 pixels resolution. Device calibration process was validated for all participants using a set of five fixed targets with uniform distribution based on the application of fuzzy C-means (FCM) clustering algorithm (Bezdek, 1981) before and after the presentation of the experimental stimuli (see also Krassanakis et al., 2016 for more details). The experimental gaze datasets were used for further analysis only if their overall spatial accuracy reported in the validation procedure corresponds to values equal or lower to the range of fovea vision (1° degree of the visual field). Fixation detection process was performed based on the application of the dispersion-based algorithm implemented in both EyeMMV (Krassanakis et al., 2014) and LandRate (Krassanakis et al., 2018) toolboxes using a value of spatial parameter ($t_1 = t_2$, see also Krassanakis et al. 2014; 2016 for more details) that corresponds to approximately 1° of visual angle (the threshold is defined in pixels) and the value of 100 ms as minimum fixation duration threshold.

2.2.3. Participants and procedure

In total, 25 participants (with normal vision) participated in the eye tracking experiment. The expertise of all participants was related to cartography and relative fields at several levels (including university students, personnel and professors). None of them had any prior knowledge regarding the procedure – other than a simple, formal notification that the stimuli depict parts of earth's surface – in order to undergo free, spontaneous looking without any task constraints, so that their attention would be involuntarily caused by the image characteristics of each stimulus (Castner and Eastman, 1984). Following the performance of the relative accuracy tests (see also paragraph 2.2.2), only the gaze data of fifteen (15) of them were used for the performed analysis. After a brief introduction to the experimental process and the calibration of each participant with the eye tracking equipment, each of them observed (under free viewing conditions) the designed stimuli, which were presented randomly on the stimuli monitor for 10 seconds per stimulus.

2.3. Expert judgement procedure for eliciting knowledge

2.3.1. Expert judgement procedure

Expert judgement is a practice whereby qualified individuals (i.e. experts) in a certain scientific or professional domain provide data and information that, in turn, can aid in problem-solving and/or in decision-making (Meyer and Booker, 2001). Widely used in technical fields, it is chosen when other sources of eliciting knowledge (e.g. observations, experimentation etc.) are unavailable, or do not fit the pertinent "phenomenon" due to its complexity, rarity or fuzziness, yet decisions must be made (Misthos et al., 2017).

In this research study, experts in the domain of geoinformatics, cartography and geovisualization (Group A), and experimental psychology, cognitive science, neuroscience and eye tracking (Group B) were invited to participate in a questionnaire-based survey (see paragraph 2.3.2) with an ultimate goal to rank different hill-shading techniques/representations taking into consideration map complexity and ETMs. The main information required was the level of relevance of each of some pre-selected ETMs, according to the opinion of each expert. In turn, this knowledge was utilized to specify which metrics and with what weightings these metrics would be participating in the aggregate index of the model (LRI). This practice is in line with one of the indicative applications of expert judgement, that is "selecting input and response variables for a chosen model" (Meyer and Booker, 2001: xxi). Since expertise is related to – but not totally determined by – experience (Patel et al., 1999), the experience of each participant in the domain was also taken into consideration; years of experience up to 20 years were normalized to correspond to the range between 0 and 1, while in cases of > 20 years, the relative coefficient was assigned the value of 1 (maximum).

2.3.2. Questionnaire's design

Towards the elicitation of experts' knowledge, an online questionnaire was designed where participants were asked to read very carefully some preparatory sections in order to assimilate all the background information needed for the questionnaire completion. A short description of this research regarding the hypothesized relation between hill-shading representations and gaze behaviour was given, providing, at the same time, an indicative example of two hill-shaded maps (also used in the eye tracking experiment as stimuli) manifesting different visual complexity levels. This section was followed by more detailed information about eye movements and the analysis of ETMs; a list of six relevant ETMs (total number of fixations: m_1, average fixation duration: m_2, average saccade length: m_3, total scanpath duration: m_4, total scanpath length: m_5, ratio of saccade duration/fixation duration: m_6) along with their interpretation was also provided in this section (See APPENDIX for these introductory parts of online questionnaire). Since this piece of information was provided, both groups are considered to have adequately understood the meaning of these ETMs. Then, instructions were given to the participants regarding the rationale to complete the fifth section of the questionnaire. Participants were asked to choose (i) the level of influence, ranging from strong negative (-3) to strong positive ($+3$), and (ii) the level of confidence, set to: slightly (1), moderately (2) or very certain (3), corresponding to each one of the ETMs. Participants were also asked to provide some personal background or demographic information. Totally, 41 respondents (15 female, 25 male, one respondent preferred not to register gender, ages from 21 to 78 years, mean: 41.1, std: 14.1) completed the questionnaire, mostly from Europe, but also from the Americas, Asia and Oceania.

3. Results

3.1. Eye tracking data

The average values for the selected ETMs were calculated after filtering the raw gaze data. Filtering process referred to the selection of the raw gaze point data which corresponded to the region covered only by the stimuli presentation area. The resulted values are presented in Table 1. Additionally, heatmap visualizations were produced in order to highlight the most observed areas (Figure 2).

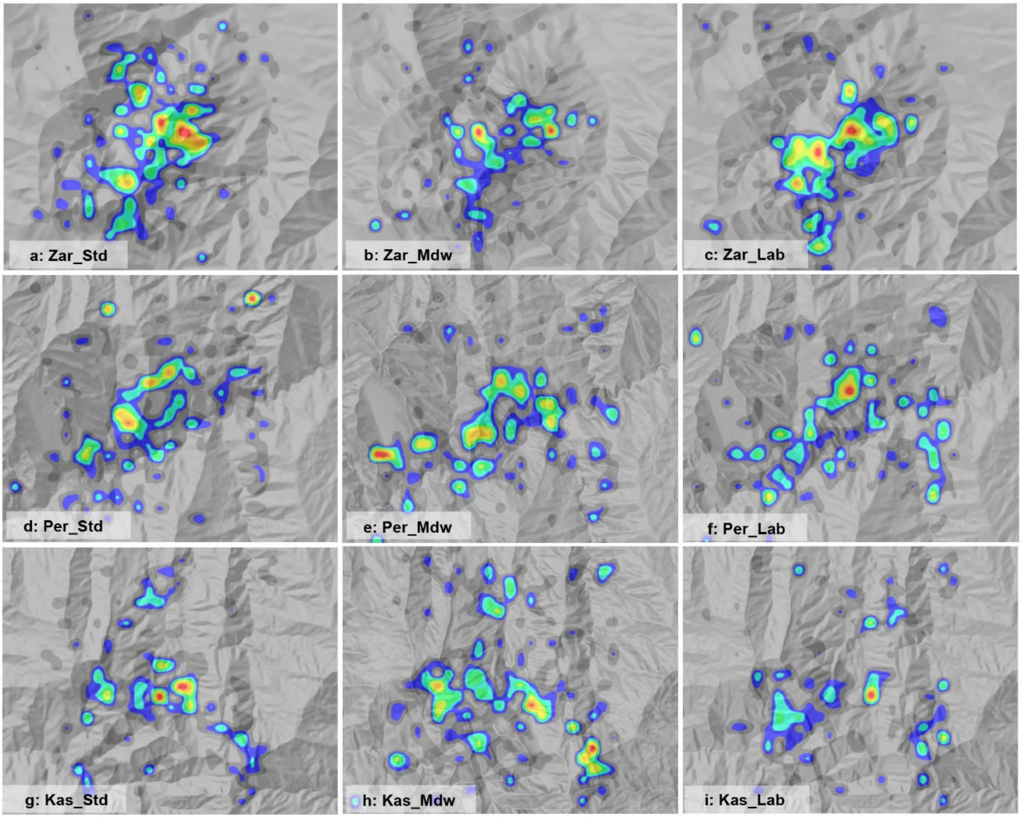

Fig. 2. Heatmap visualizations based on the gaze data of all participants

3.2. Questionnaires' analysis

The numerical scales explained in Subsections 2.3.1 and 2.3.2 were used to replace the descriptive answers of the respondents to the online questionnaire, allowing for the appropriate quantitative analysis. For each participant and ETM, the level of confidence was multiplied with the level of influence and the expertise coefficient, while final rating weights for each of the selected utilized ETMs were computed as averages of all participants (Table 1). The produced values were normalized as described in Krassanakis et al. (2018). The calculations were also carried out separately for each group of experts (A and B).

Table 1. Average values of ETMs chosen (before normalization) with their average and normalized average weights (coefficients of LRI)

Stimuli	Total number of fixation	Average fixation duration [ms]	Average saccade length [px]	Total scanpath length [px]	Total scanpath duration [ms]	Ratio saccades/fixations (durations)
Kas_Std	24.07	322.20	212.08	4972.31	9793.61	0.37
Kas_Mdw	26.53	289.18	214.17	5447.68	9801.82	0.31
Kas_Lab	24.40	312.97	221.43	5188.45	9572.09	0.30
Per_Std	25.00	309.67	226.28	5444.89	9789.67	0.33
Per_Mdw	26.00	294.91	208.67	5238.63	9826.23	0.34
Per_Lab	24.67	315.80	212.91	5016.06	9878.30	0.34
Zar_Std	25.20	306.12	199.21	4917.79	9519.49	0.28
Zar_Mdw	24.87	323.78	198.26	4823.89	9735.27	0.32
Zar_Lab	23.73	307.21	208.72	4796.26	9697.83	0.38
GROUP A weights						
Average	0.21	0.23	0.09	0.04	0.02	0.08
Norm. average	0.313	0.347	0.135	0.024	0.066	0.115
GROUP B weights						
Average	0.14	0.14	0.04	0.12	0.06	0.08
Norm. average	0.243	0.240	0.070	0.104	0.204	0.138
OVERALL weights						
Average	0.18	0.19	0.07	0.08	0.04	0.08
Norm. average	0.283	0.301	0.108	0.060	0.123	0.123

3.3. LRI modeling

Finally, the values of LRI were estimated for the nine (9) stimuli, based on answers of participants in Group A, Group B and the total of them (Figure 3). The produced LRI models are respectively described in the following Eq. (2), Eq. (3) and Eq. (3). The values of the parameters m_1, m_2, m_3, m_4, m_5, and m_6 were normalized based on the typical linear model for data normalization. According to this model, all the corresponded values are divided by the maximum one. Hence, the maximum value is equal to 1.

$$\mathrm{LRI} = 0.313 \cdot m_1 + 0.347 \cdot m_2 + 0.135 \cdot m_3 + 0.024 \cdot m_4 + 0.066 \cdot m_5 + 0.115 \cdot m_6 \tag{2}$$

$$\mathrm{LRI} = 0.243 \cdot m_1 + 0.24 \cdot m_2 + 0.07 \cdot m_3 + 0.104 \cdot m_4 + 0.204 \cdot m_5 + 0.138 \cdot m_6 \tag{3}$$

$$\mathrm{LRI} = 0.283 \cdot m_1 + 0.301 \cdot m_2 + 0.108 \cdot m_3 + 0.06 \cdot m_4 + 0.123 \cdot m_5 + 0.123 \cdot m_6 \tag{4}$$

Fig. 3. LRI values for the nine evaluated hill-shading images

4. Discussion and conclusions

The concept of perceived visual complexity is here utilized for comparing images of topographic relief representation with multidirectional hill-shading. In order to quantify this comparison, a weighted combination of basic eye tracking metrics (ETMs) has been used, implemented by the LRI (Landscape Rating Index). The weights resulted from an experts' judgement questionnaire, which was answered by experts in cartography and visual perception related domains. The production of the three LRI models as well as the calculation of the corresponding LRI values indicate that the perceived visual complexity of the implemented multidirectional and single-source hill-shading methods are nearly the same. This finding may seem surprising – or even frustrating – for images (hill-shading representations) with objectively different levels of information richness and complexity. One might expect that different hill-shading representations (with different complexity levels) would yield significantly different subjective rankings. However, it turns out that the "objectively" more complex relief representations (i.e. multidirectional hill-shading) containing richer and more (useful) information is not more complex in subjective terms – at least for the representations under study.

Hence, implementing hill-shading with more than one light source seems to retain the elements of realism and functionality in communicating relief's shapes, allowing for additional, strong exposure of relief details, or even whole forms, which could not benefit from one only light source. In other words, the similar LRI modelling values – under the methodology described in this paper – may be an evidence for using multidirectional hill-shading without the risk that it would be too complex for users to apprehend and interpret. The outcomes reported above constitute some preliminary results, while next step includes the performance of in-depth statistical analysis on the collected data of both eye tracking and experts' answers. Moreover, this methodology should be tested in the future on different types of landscapes (e.g., volcanic, glacial, etc.) or even on different types of visualizations (e.g., oblique perspective views/photographs, topographic maps, simulated images, etc.).

The present study constitutes a part of an ongoing research which aims to highlight how much could multidirectional hill-shading affect the visual perception during map reading. Desired goals of the research are to develop enhanced multidirectional hill-shading variants and mostly, to analytically express their rational intervention in the "problematic" areas of hidden relief information coming up in formal, single-source hill-shading, in the context of which also a task-specific survey/experiment is being planned.

Author contributions

Conceptualization: N.T., A.K., V.K., L.-M.M. and B.N.; Eye tracking experiment performance: A.K., Methodology development: N.T., V.K. and L.-M.M.; Questionnaire development and analysis: N.T., V.K. and L.-M.M.; Eye tracking data analysis and software: N.T., V.K. and L.-M.M.; Writing – original draft: N.T., A.K., V.K. and L.-M.M.; Writing – review and editing: N.T., V.K., L.-M.M. and B.N.

Data availability

The experimental stimuli, the filtered raw eye tracking data, the questionnaire data as well as the LandRate toolbox reports for both Groups (A and B) and the overall report (both Groups) are distributed online at http://users.ntua.gr/niktzel/gc_ paper_data.zip.

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APPENDIX

Parts of the online questionnaire explaining the overall goal (Page 1), describing the research (Page 2) and describing/explaining the eye tracking process/metrics (Page 3) are displayed below.

Relief shading evaluation based on eye movement analysis

Dear participant,

This study constitutes an expert judgement process which is a part of a research work that takes place at the Cartography Lab. of National Technical University of Athens and aims to examine how people perceive different topographic relief shading methods.

You are kindly requested to read very carefully the first four sections, which give all the important background information that you need in order to complete a questionnaire (section 5). In section 6 you are also kindly asked to fill in with a few relevant demographic information, while in section 7 you can optionally add any comments.

All the data are collected anonymously and will be used only for scientific research/purposes.

Thank you for your participation!

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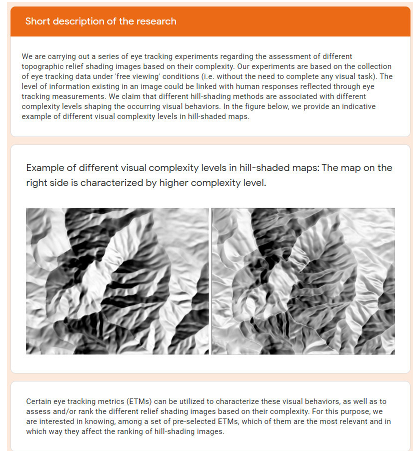

Short description of the research

We are carrying out a series of eye tracking experiments regarding the assessment of different topographic relief shading images based on their complexity. Our experiments are based on the collection of eye tracking data under 'free viewing' conditions (i.e. without the need to complete any visual task). The level of information existing in an image could be linked with human responses reflected through eye tracking measurements. We claim that different hill-shading methods are associated with different complexity levels shaping the occurring visual behaviors. In the figure below, we provide an indicative example of different visual complexity levels in hill-shaded maps.

Example of different visual complexity levels in hill-shaded maps: The map on the right side is characterized by higher complexity level.

Certain eye tracking metrics (ETMs) can be utilized to characterize these visual behaviors, as well as to assess and/or rank the different relief shading images based on their complexity. For this purpose, we are interested in knowing, among a set of pre-selected ETMs, which of them are the most relevant and in which way they affect the ranking of hill-shading images.

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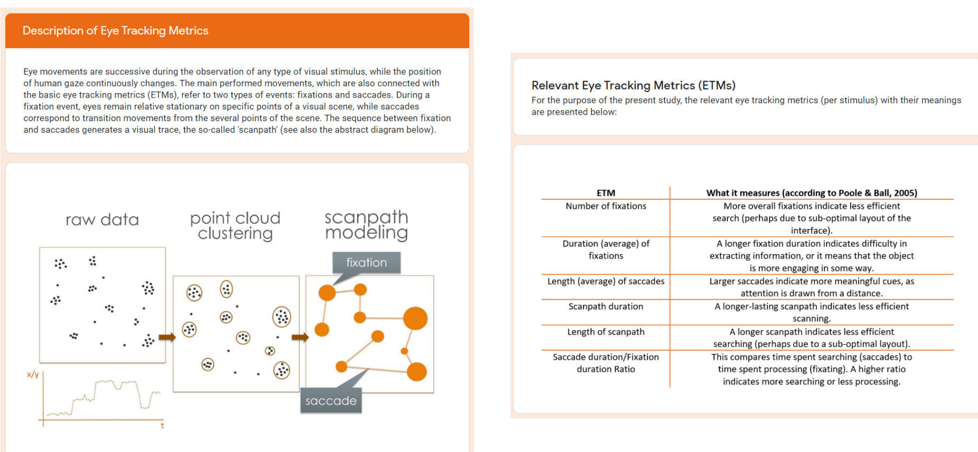

Description of Eye Tracking Metrics

Eye movements are successive during the observation of any type of visual stimulus, while the position of human gaze continuously changes. The main performed movements, which are also connected with the basic eye tracking metrics (ETMs), refer to two types of events: fixations and saccades. During a fixation event, eyes remain relative stationary on specific points of a visual scene, while saccades correspond to transition movements from the several points of the scene. The sequence between fixation and saccades generates a visual trace, the so-called 'scanpath' (see also the abstract diagram below).

Relevant Eye Tracking Metrics (ETMs)

For the purpose of the present study, the relevant eye tracking metrics (per stimulus) with their meanings are presented below:

ETM	What it measures (according to Poole & Ball, 2005)
Number of fixations	More overall fixations indicate less efficient search (perhaps due to sub-optimal layout of the interface).
Duration (average) of fixations	A longer fixation duration indicates difficulty in extracting information, or it means that the object is more engaging in some way.
Length (average) of saccades	Larger saccades indicate more meaningful cues, as attention is drawn from a distance.
Scanpath duration	A longer-lasting scanpath indicates less efficient scanning.
Length of scanpath	A longer scanpath indicates less efficient searching (perhaps due to a sub-optimal layout).
Saccade duration/Fixation duration Ratio	This compares time spent searching (saccades) to time spent processing (fixating). A higher ratio indicates more searching or less processing.

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References

Bezdek, J.C. (1981). *Pattern Recognition with Fuzzy Objective Function Algoritms*. New York, USA: Plenum Press.

Castner, H.W. and Eastman, R.J. (1984). Eye-movement parameters and perceived map complexity – I. *The American Cartographer*, 11(2), 107–117. DOI: 10.1559/152304084783914768.

Farmakis-Serebryakova, M. and Hurni, L. (2020). Comparison of Relief Shading Techniques Applied to Landforms. *ISPRS Int. J. Geo-Inf.*, 9(3), 253. DOI: 10.3390/ijgi9040253.

Horn, B.K.P. (1981). Hill-shading and the reflectance map. *Proc. IEEE*, 69(1), 14–47. DOI: 10.1109/PROC.1981.11918.

Imhof, E. (1982). *Cartographic Relief Presentation*. Berlin, Germany: Walter de Gruyter.

Kaplan, R. and Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge, UK: Cambridge University Press.

Kennelly, P.J. and Stewart, A.J. (2006). A uniform sky illumination model to enhance shading of terrain and urban areas. *CaGIS,* 33, 21–36. DOI: 10.1559/152304006777323118.

Kennelly, P.J. and Stewart, A.J. (2014). General sky models for illuminating terrains. *Int. J. Geogr. Inf. Sci.*, 28, 383–406. DOI: 10.1080/13658816.2013.848985.

Kiefer, P., Giannopoulos, I., Raubal, M. and Duchowski, A. (2017). Eye tracking for spatial research: Cognition, computation, challenges. *Spat. Cogn. Comput.*, 17(1–2), 1–19. DOI: 10.1080/13875868.2016.1254634.

Krassanakis, V. and Cybulski, P. (2019). A review on eye movement analysis in map reading process: The status of the last decade. *Geodesy Cartogr.*, 68(1), 191–209. DOI: 10.24425/gac.2019.126088.

Krassanakis, V., Filippakopoulou, V. and Nakos, B. (2014). EyeMMV toolbox: An eye movement post-analysis tool based on a two-step spatial dispersion threshold for fixation identification. *J. Eye Mov. Res.*, 7(1). DOI: 10.16910/jemr.7.1.1.

Krassanakis, V., Filippakopoulou, V. and Nakos, B. (2016). Detection of moving point symbols on cartographic backgrounds. *J. Eye Mov. Res.*, 7(1). DOI: 10.16910/jemr.9.2.2.

Krassanakis, V., Misthos, L.M. and Menegaki, M. (2018). LandRate toolbox: An adaptable tool for eye movement analysis and landscape rating. In *Eye Tracking for Spatial Research: 3rd International Workshop*, 14 January 2018 (pp. 40–45). Zurich, Switzerland: ETH Zurich Research Collection.

Kuper, R. (2017). Evaluations of landscape preference, complexity, and coherence for designed digital landscape models. *Landsc. Urban Plan.*, 157, 407–421. DOI: 10.1016/j.landurbplan.2016.09.002.

Loissios, D., Tzelepis, N. and Nakos, B. (2007). A methodology for creating analytical hill-shading by combining different lighting directions. In *Proceedings of 23rd International Cartographic Conference*, 4-10 August 2007. Moscow, Russia: International Cartographic Association.

Machado, P., Romero, J., Nadal, M., Santos, A., Correia, J. and Carballal, A. (2015). Computerized measures of visual complexity. *Acta Psychol.*, 160, 43–57. DOI: 10.1016/j.actpsy.2015.06.005.

Mark, R. (1992). *Multidirectional, oblique-weighted, shaded-relief image of the Island of Hawaii*. U.S. Geological Survey. (OF-92-422).

Meyer, M.A. and Booker, J.M. (2001). *Eliciting and analyzing expert judgment: a practical guide*. Philadephia, USA: Society for Industrial and Applied Mathematics.

Misthos, L.M., Messaris, G., Damigos, D. and Menegaki, M. (2017). Exploring the perceived intrusion of mining into the landscape using the fuzzy cognitive mapping approach. *Ecol. Eng.*, 101, 60–74. DOI: 10.1016/j.ecoleng.2017.01.015.

Patel, V.L., Arocha, J.F. and Kaufman, D.R. (1999). Expertise and Tacit Knowledge in Medicine. In R.J. Sternberg and J.A. Horvath (Eds.), *Tacit Knowledge. in Professional Practice: Research and Practitioner Perspectives* (pp. 75–99). New Jersey, USA: Lawrence Erlbaum Associates Publishers.

Pieters, R., Wedel, M. and Batra, R. (2010). The stopping power of advertising: Measures and effects of visual complexity. *J. Mark.*, 74(5), 48–60. DOI: 10.1509/jmkg.74.5.048.

Veronesi, F. and Hurni, L. (2015). A GIS tool to increase the visual quality of relief shading by automatically changing the light direction. *Comput. Geosci.*, 74, 121–127. DOI: 10.1016/j.cageo.2014.10.015.